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AN OVERVIEW OF FLEXIBLE MANUFACTURING SYSTEMS TECHNOLOGY WORLDWIDE

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AN OVERVIEW OF FLEXIBLE MANUFACTURING SYSTEMS TECHNOLOGY WORLDWIDE*

by

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INTRODUCTION

This overview covers the definitions and types of Flexible Manufacturing Systems (FMS), their applications, major technologies and subsystems, key factors for success, a list of selected manufacturers worldwide, and the current trends in this field. Attached to this brief summary of the presentation are some of the key charts used by the author during seminars.

There are no generally agreed upon definitions and each company or industry group uses slightly different definition; the attached definitions are typical. FMS's can be categorized in many ways such as these listed in the first two charts. The definitions given in Chart 2 are arbitrary and any other set of consistent definitions would be satisfactory. The emphasis in FMS is on the combination of automatic machines, common material handling system, common computer control and the ability to randomly process batches of different parts belonging to one or more common part families. Note that the abbreviation FMS stands both for Flexible Manufacturing and Flexible Machining System. There is also a category I call a Pseudo-FMS; it lacks some of the key features found in a full fledged FMS, for example it may not have fully automatic material handling or full controls or it may include some manual machine tools. It is usually lower in cost, but not as versatile. These Pseudo-FMS's fill an important market area and are indeed useful.

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Applications

The FMSs are essentially limited in their applications to discrete mechanical type hardware, such as the fabrication of metal parts, the assembly of components or the manufacture and inspection of "hard goods". It does not apply to the manufacture of raw materials (e.g. chemicals, minerals, paper). However it applies to the fabrication of parts and assemblies in those industries shown in Chart 3. The initial applications were largely in the construction machinery and vehicle areas, but the number of industries has increased greatly. Additional FMS applications in other industries are likely.

Technology

The technology for operating, developing and improving FMS covers from many fields. Chart 4 shows some of these areas. There is really very little technology that is peculiar to FMSs or automated fabrication; most is borrowed or adapted from other fields. In fact advances in computers, electronics, cutting tools, power transfer or part handling have made the FMS possible.

The technology of FMS can also be described in terms of its principal subsystems, namely the machine tools or fabrication equipment, the material handling system, the control system, the tooling subsystem, the coolant supply and reconditioning subsystem, the chip handling system and the automatic storage/retrieval system.

The machine tools basically are the same as those used for stand-alone machines. Since they are loaded and unloaded automatically, they no longer need features that allow an operator to conveniently load or service the equipment. Chart 5 shows different types of machines that have been used in an FMS.

There is a wide variety of material handling and transfer devices that have been used with FMS. As shown in Chart 6, each has advantages for certain types of parts and operations.

The control system design is governed by its complexity (which relates to the different number and types of automated functions within the FMS), by its number of computers and tiers (hierarchies), or by its use of existing commercial electronic control systems (PC, CNC, DNC, etc.). Chart 7 shows typical functions of an FMS-control subsystem. These controls can be redundant (e.g. dual system, so if one fails, the other one will still control) or non-redundant. The control system can include or not include special diagnostics (to assist in the identification of internal failures), special priority logic (to assist in the selection and sequence for processing jobs and to reduce idle time), or the storage of parts, tools or fixtures.

The chip handling systems and cutting fluid systems can be manual (each machine is serviced separately; the chips are put into a cart which is hauled away or the cutting fluid is replaced by a hose from a mobile tank cart) or it can be a centralized system. Often automatic conveyors transport the chips from each machine to a central collection location where they are drained of cutting fluid, compacted and prepared for shipment. From a centralized cutting fluid system the cutting fluid is pumped and distributed to each machine and the used fluid is collected, filtered and repumped.

In this central location the fluid is cleaned and make-up solution is added to compensate for losses due to evaporation or chip adhesion. The central systems have the advantage that they are usually better controlled, give better quality and less labor intensive, but they have the disadvantage that a failure in the central system shuts down all the machine tools.

The tool handling (see Chart 8) includes the replacement of worn tools with new or reconditioned tools plus their reconditioning. The replacement can be manual (operator stops machine and replaces tool), or with an automatic tool changer and a tool magazine on each machine tool. Transport of tools (or complete tool magazines) between the machine and the tool reconditioning area can be manual (hand-carts, power-driven cars) or automatic (by conveyor or unmanned cart). Tool reconditioning also can be manual or partly automated with CNC tool grinders. Tool wear monitoring and tool failure monitoring can be included as automatic options.

The storage of fixtures, pallets, raw materials, dies, or other tooling can be remote (when it is not needed regularly), close by (easier access), or on-line (e.g. tied into material handling system). Automatic retrieval may in many cases be preferred over manual retrieval from storage.

The AMS and each of its 3 categories can be broken down by the fabrication processes they use such as machining, welding, sheet metal, assembly, forming/pressing, and others. It is possible to interconnect several FMSs; for example, 2 flexible machining systems can be feeding parts to a flexible assembly system.

Classification of FMS

"Classification" is the systematic sorting or arranging of items into types or categories with related characteristics. This classification thus gives an insight into the varieties, commonalities and differences between various types of FMS. I have found that use of the module, cell and flexible system to be convenient. In a simplified way one can think of a Module as a single machine tool flexible manufacturing system, an automated cell as one with perhaps 2 to 3 machine tools and a Flexible System as one with 4 or more machine tools. There are, for example, turning modules, milling modules or welding modules. Charts 9, 10 and 11 show simplified diagrams of these systems.

There are many other ways to classify FMSs, including those shown on Chart 12. This list of FMS types is certainly not complete or all-inclusive. Each of these methods of classifications will now be briefly discussed.

The part size or weight obviously affects the size of the machines, their speeds and the type of material handling. One can speak of "large" and small FMSs. Heavy parts are difficult to move and set up, high accuracy is more difficult to achieve, and only some material handling systems can handle them satisfactorily. For example very heavy parts have been handled by special heavy rail mounted pallet-carts, (but not by robots) since this allows accurate indexing of the Parts axes to the machine axes. For heavy parts, the work stays locked to a stationary fixture and usually the tool moves.

Part Complexity obviously affects the number and variety of processes or machines in the systems, or the holding of the part during fabrication. An FMS designed for simple parts usually is not capable of making a more complex part, and a system designed for a complex part requiring several different processes, will be too expensive in its operation to allow simple parts to also be fabricated on it. So people talk about simple and complex systems. The group technology relationship is important in selecting part families for FMS. Group Technology allows parts with similar characteristics to belong to the same part family. The similar characteristics can be one or more of these; similar geometry, fabrication processes, materials or functions (design purpose, such as shafts, gears, boxes, brackets, etc.). There are FMS categories to fit specific part families.

Another classification is by type of process. Chart 8 shows a variety of processes (each with its own peculiar fabrication equipment) that have already been used in at least one existing FMS. A number of other processes can be or have also been adapted to FMS applications.

The order quantities, through-put and batch sizes influence the type and number of automatic machines in any one FMS. With large parts the quantities are usually small, but with smaller parts the total annual volume flow is usually large. The larger variety of products puts an emphasis on features that allow rapid change over to the next part. The batch size has an influence on the degree of dedication. Large batches seem to foster more specialized features such as pallets, fixtures, special tooling or dedicated machines.

Another way to classify FMSs is by the basic geometry of the material handling flow path and thus the relative location of the machine tools. One can distinguish between closed loop systems (where pallets return and can be recycled) and open loop system where the flow is unidirectional. There are those with multiple loops to help with recycling of pallets to specific machines on special features.

Another simple method of distinguishing FMS's is by the degree of operator attention it receives. People talk about a "manned" or "unmanned" FMS. While there are quite a number of systems that can run without operator for a period of time (e.g. for a few hours up to several shifts) there is no system as yet that can run truly unmanned for longer than a day or two. It is perhaps more correct to say that there are FMS designs that are (1) always manned by at least one part-time operator on every shift even if he is only a monitor or corrector of occasional problems, such as fixing a jammed conveyor or a broken tool or (2) are truly unmanned for a relatively short period only, e.g. during the swing and night shift.

The key to unmanned FMS operation is (1) high reliability in all the subsystems and their components and (2) automatic recovery of the system or subsystem from anticipated failures. An example of recovery is the sensing of a broken drilling tool, the automatic stopping of the machine and identifying and unloading of the part with the broken drill bit, replacing the broken tool with another identical tool already stored in the magazine, loading a new part, and resuming CNC operation on the new part.

Worldwide FMS Developments

Many of the developed countries have companies who have built FMS installation, often not only for their own country but also for export. The Japanese, Germans, and Italians as well as firms from other countries have successfully sold FMSs in the USA. The Japanese probably have built more FMSs than builders in any other country and they have pioneered unmanned applications. The Germans have probably built some of the most sophisticated FMSs to date. So the worldwide competition is intense. The partial lists in Chart 13 and 14 show some of the key FMS builders; several other countries are in the process of entering this field.

The FMS capability in the USSR and the Eastern Block countries is significant and all of these FMS developments are essentially financed by the Government. As of now they (USSR, Poland, Czechoslovakia, East Germany) have not exported any systems outside the Soviet areas.

Many of the countries directly subsidize FMS systems by grants, outright purchase or support of industry research and development. Various countries have been spending up to 20 Million per year of Government funds in this area. In the USA there is no direct support of FMS to industry, however, various Government agencies (Army, Air Force, NBS, NSF, Navy) support their missions with Federal Funds for studies, and R&D efforts at a level of between 3 and 6 Million dollars annually.

It is difficult to determine the total number of FMS systems; estimates vary from 230 to 350 worldwide. There is agreement however that the rate at which they are being produced has generally been increasing and that new types of FMS are being developed steadily for different applications

Conclusion

FMSs are certainly not for everyone and they are not a panacea for all manufacturing. In many applications manual or automatic stand-alone machine tools may do a better job. And sometimes a pseudo - FMS is better and more cost-effective.

FMSs are here to stay. Their viability has now been proven in many applications and the number of systems and the number of suppliers has risen greatly in the last 5 years. Foreign competition has been increasing. All this is because of the benefits or merits of the FMS. Chart 15 shows a list of benefits that have been used to justify an FMS.

Even if the application, part family and order quantities are right for a FMS, there are still many pitfalls to avoid on the way to a successful FMS, as shown in Chart 16. If some of these key ingredients are missing, then even a well conceived FMS may turn out to be a failure.

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CLASSIFICATION OF AUTOMATIC MANUFACTURING SYSTEMS

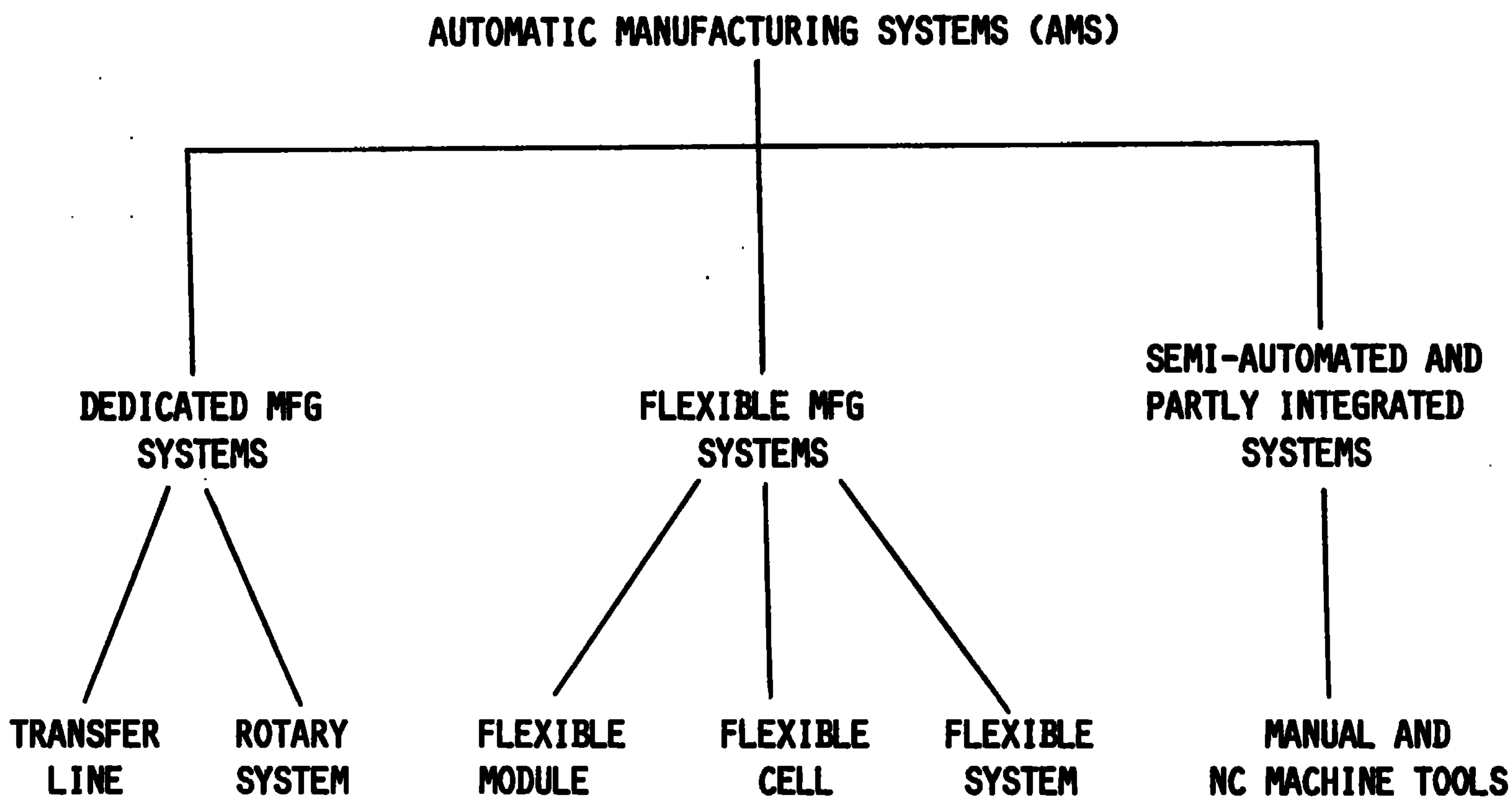


CHART 1

DEFINITIONS

AUTOMATIC MANUFACTURING SYSTEM

ONE OR MORE MODULES OF AUTOMATED MANUFACTURING EQUIPMENT CAPABLE OF PERFORMING MANUFACTURING PROCESSES (SUCH AS MACHINING, WELDING OR ASSEMBLY) INTEGRATED WITH AUXILIARY EQUIPMENT (MATERIALS HANDLING, STORAGE, FAILURE DETECTION) DESIGNED TO AUTOMATICALLY MANUFACTURE PARTS OR PRODUCTS.

FLEXIBLE MANUFACTURING SYSTEM (FMS)

AN AMS CONSISTING OF SEVERAL ITEM OF AUTOMATED FABRICATION EQUIPMENT AND A COMMON MATERIAL HANDLING SYSTEM, SUPERVISED BY A COMMON COMPUTER AND DESIGNED TO RANDOMLY MANUFACTURE OR ASSEMBLE PRODUCTS BELONGING TO A COMMON PART FAMILY.

FLEXIBLE MACHINING SYSTEM (FMS)

AN AUTOMATIC MACHINING SYSTEM CONSISTING OF ONE OR MORE MACHINE TOOLS AND A COMMON MATERIAL HANDLING SYSTEM, SUPERVISED BY A COMMON COMPUTER AND DESIGNED TO RANDOMLY MACHINE BATCHES OF PARTS BELONGING TO A COMMON PART FAMILY.

DEDICATED MACHINING SYSTEM (DMS)

ONE TYPE OF AUTOMATIC MACHINING SYSTEM USED FOR MAKING LARGE BATCHES OF THE SAME PART (OR A FEW SIMILAR PARTS). THE DMS CATEGORY INCLUDES A TRANSFER LINE OR A ROTARY MACHINING SYSTEM.

CELL

A GROUP OF CLOSELY LOCATED AND RELATED MACHINE TOOLS OR MODULES OF PRODUCTION EQUIPMENT USED TO MANUFACTURE A GROUP OF DIFFERENT, BUT RELATED PARTS.

MODULE

AN AUTOMATIC MACHINE TOOL WITH ITS OWN STORAGE AND MATERIALS HANDLING SUBSYSTEM.

CHART 2

TYPICAL INDUSTRIES WITH FMS APPLICATIONS

AEROSPACE COMPONENTS
AIR CONDITIONING EQUIPMENT
AGRICULTURAL MACHINERY
AUTOMOTIVE VEHICLES
    ENGINES, TRANSMISSIONS
COMPRESSORS AND FANS
CONSTRUCTION MACHINERY
CUTTING TOOLS
DIESEL ENGINES
ELECTRIC MOTORS/ALTERNATORS
ELECTRO-OPTICAL AND COMPUTER HOUSING
FASTENERS
GEARS AND GEAR BOXES
HYDRAULIC SYSTEM COMPONENTS

MACHINE TOOLS
MEASURING INSTRUMENTS
MINING MACHINERY
OFF-ROAD VEHICLES
PRESSURE REGULATORS
PRINTING MACHINERY
PUMPS
RAILROAD AXLES AND WHEELS
ROBOTS
SHEET METAL BOXES/CABINETS
SHOE FABRICATION MACHINES
TEXTILE MACHINERY
TOOL HOLDERS
TURBINE COMPONENTS
VALVES

CHART 3

Machining systems—a functional map

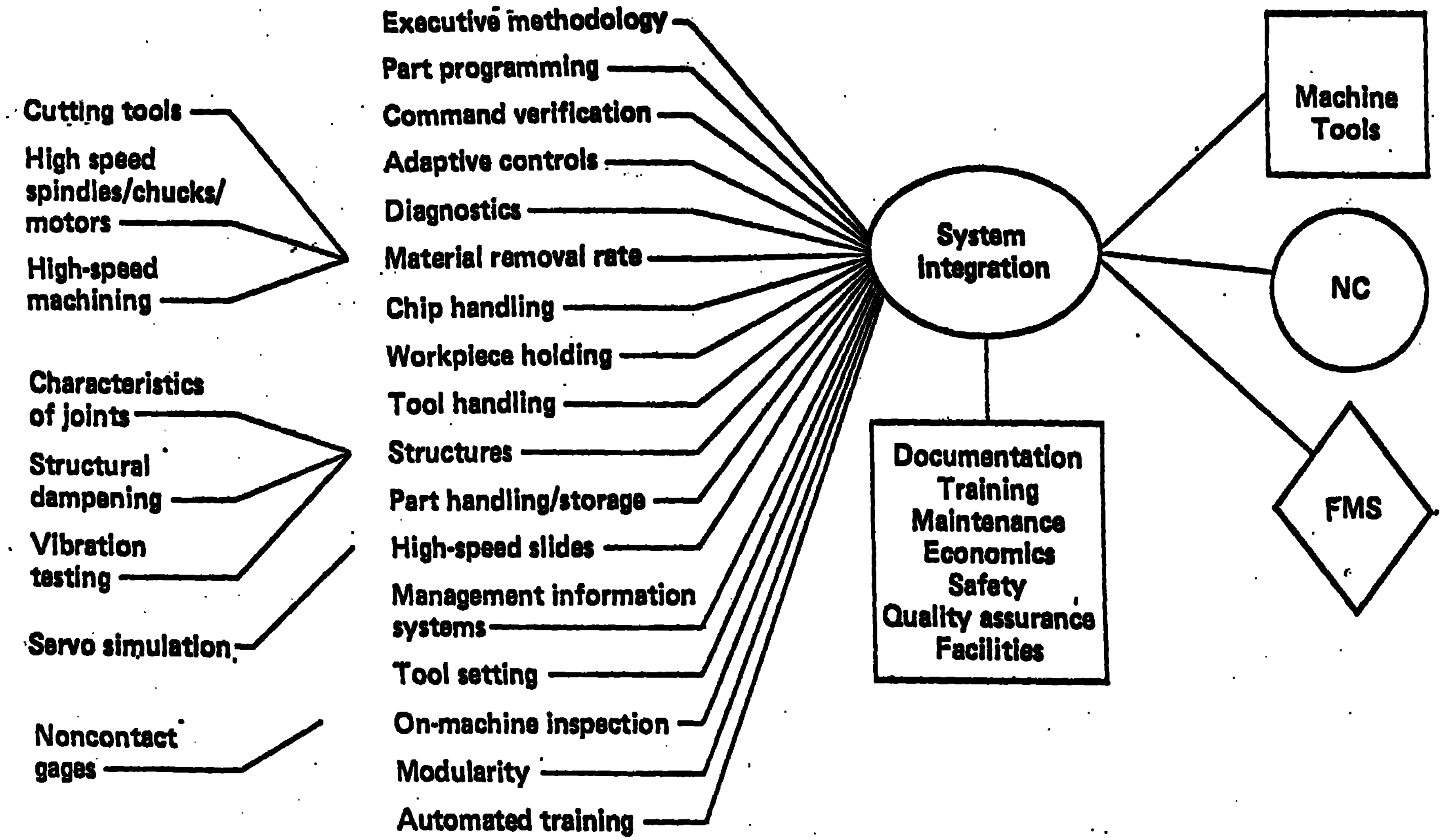


CHART 4

TYPICAL PROCESSES AND FABRICATION EQUIPMENT USED IN AT LEAST ONE EXISTING FMS

TYPICAL PROCESS	TYPICAL EQUIPMENT
TURNING CHUCKERS	LATHES, VERTICAL TURNING MACHINES,
MILLING VERTICAL MACHINING CENTERS	MILLING MACHINES, HORIZONTAL AND
DRILLING/TAPPING/SPOT FACING CHANGERS	SAME PLUS DRILLING MACHINES, HEAD
WELDING SPOT WELDERS	ARC WELDERS, GAS WELDERS,
HEAT TREATMENT EQUIPMENT	FLAME HARDENING, LASER HARDENING
CUTTING MACHINE, FLAME CUTTER	SHEARS, PUNCH PRESS, PLASMA ARC
FORMING SWAGING MACHINE, TUBE BENDING MACHINE	ROLLING MACHINE, BENDING MACHINES
CLEANING	RINSE/WASH MACHINE
DEBURRING/FINISHING BRUSHING	CERAMIC STONE TUMBLING, WIRE
GEAR PROCESSING GEAR SHAPERS	BLANKING MACHINES, GEAR CUTTERS,

CHART 5

TYPICAL PROCESSES AND FABRICATION EQUIPMENT USED IN AT LEAST ONE EXISTING FMS - (CONTINUED)

TYPICAL PROCESS	TYPICAL EQUIPMENT
GRINDING	SURFACE GRINDERS, INTERNAL/EXTERNAL GRINDERS
ASSEMBLY	EQUIPMENT FOR PLACING AND TIGHTENING FASTENERS, JOINING EQUIPMENT, PUTTING PARTS TOGETHER
INSPECTION	VARIOUS TYPES OF AUTOMATIC GAGES
BRAZING, SOLDERING	FURNACES, FLAME MELTING OR INDUCTION HEATING EQUIPMENT
ELECTRO DISCHARGE MACHINES	HOLES, SLOTS IN VALVE PINTLES, TURBINE BLADES

CHART 5 (CONT'D)

MATERIAL HANDLING SYSTEM CHOICES

	Typical Part Weight (Pounds)	Need for Separate Fixture (Part Orienting)	Floor Obstruction	Ability to Change Parts	Distance Covered	Ease of Layout Change
Roller Conveyor	Heavy, up to 8000	Yes	Yes	Yes	Limited	Difficult
Belt Conveyor	Small to Medium, 1 to 1000	Yes/No	Yes	Yes	Limited	Difficult
Railed Vehicle	Very heavy, up to 40,000	Yes	No	Yes	Limited	Difficult
Towed Vehicle *	Very heavy	Yes	No	Yes	Limited	Difficult
Stacker Crane	Medium, up to 2,000	No	No	Limited **	Limited	Usually Easy
Self-Powered Tired Cart	Heavy, up to 8,000	Yes	No	Yes	Long Distance	Relatively Easy
Crane (Conventional)	Heavy, up to 20,000	No	No	Limited **	Limited	Easy
Forklift Truck	Heavy, up to 10,000	No	No	Yes	Unlimited	Very Easy
Robot	Low, up to 200	No	Yes	Limited **	Very Small	Harder
Monorail Carrier	Low, up to 200	No	No	Yes	Limited	Difficult

* A tow-line is a railed vehicle towed by an under-the-floor chain drive

** May need to change "hands" or "grippers"

CHART 6

FUNCTIONS OF THE FMS CONTROL SUBSYSTEM

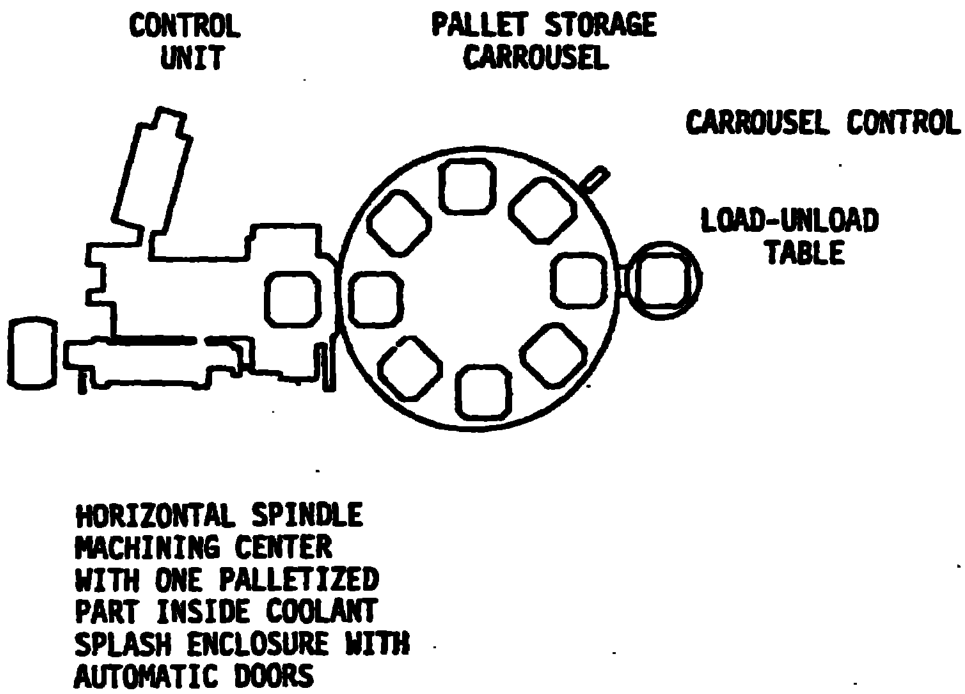
1. COMMAND AND MONITOR TOOL PATH AND MACHINE MOVEMENT
2. COMMAND THE ROUTING, MOVING AND TRANSFER OF PARTS TO DIFFERENT STATIONS (MATERIAL HANDLING)
3. CONTROL MACHINE TOOL/SYSTEM OPERATIONS (COOLANT FLOW, LUBRICATION, CHIP REMOVAL, ETC.)
4. DIAGNOSTICS FOR SENSING DRASTIC FAILURE
5. EMERGENCY STOPS OR CHANGES IN OPERATING CONDITIONS, IF FAILURE IS SENSED
6. AUTOMATIC RECOVERY FROM FAILURE
7. REDUNDANCY TO ENHANCE RELIABILITY
8. DIAGNOSTICS TO IDENTIFY CAUSE OF FAILURE PRIOR TO REPAIR
9. DATA FLOW CONTROL
10. MONITORING CONDITION/STATUS OF MACHINES, MATERIAL HANDLING, INVENTORY
11. COMMAND TOOL CHANGE, CONTROL TOOL INVENTORY OR TOOL CONDITION
12. DATA MANIPULATION FOR DESIRED OUTPUTS (ALARMS, REPORTS, DISPLAYS, SHUTDOWN)
13. STORE, REMOVE, ADD PROGRAMS
14. ACCEPT SPECIFIC OPERATOR/MANAGEMENT INPUTS (MANUAL CONTROL, PRIORITY, RE-ROUTE AROUND DOWNED MACHINE)

CHART 7

CLASSIFICATION OF TOOL SYSTEM FEATURES FOR FMS

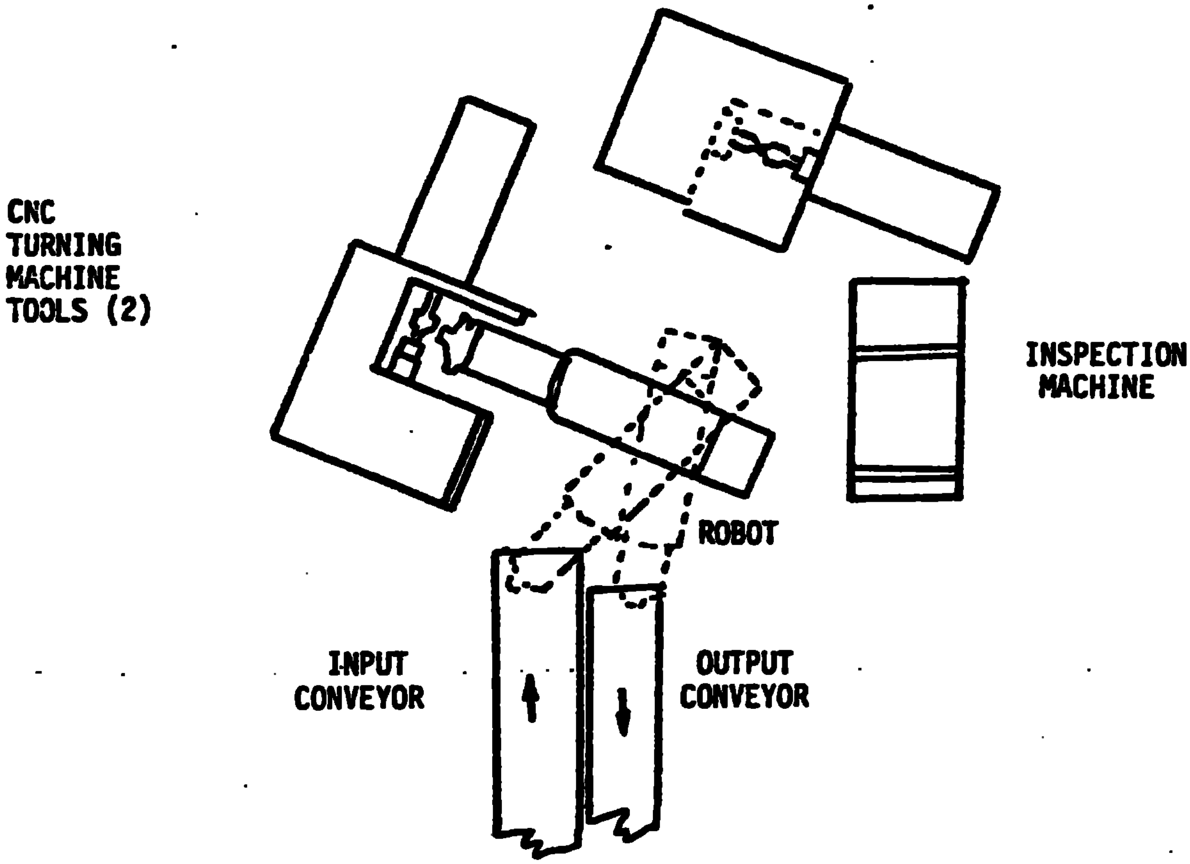
TOOL CHANGE/REPLACE	o MANUAL o AUTOMATIC
TOOL STORAGE AT THE MACHINE	o MANUAL (BOX, RACK, ETC.) o AUTOMATIC TOOL MAGAZINE LARGE (OVER 150 TOOLS) SMALL (2 TO 6 TOOLS)
TRANSPORT BETWEEN MACHINE AND TOOL RECONDITIONING AREA	o MANUAL (HAND CARTS, BOXES, POWERED MAN-DRIVEN VEHICLE) o AUTOMATIC MAGAZINE TRANSFER (CONVEYOR, UNMANNED CART)
TOOL RECONDITIONING (REMOTE)	o MANUAL o SEMI-AUTOMATIC
TOOL WEAR MONITORING & MACHINE ADJUSTMENT OR CORRECTION	o PART INSPECTION AND POST-PROCESS MANUAL ADJUSTMENT o AUTOMATIC CUTTING TIME MONITORING o PART INSPECTION ON OR OFF MACHINE AND AUTOMATIC POST-PROCESS ADJUSTMENT o PART INSPECTION AND IN-PROCESS MACHINE ADJUSTMENT
TOOL FAILURE MONITORING	o VISUAL BY OPERATOR o AUTOMATIC SENSING AND EMERGENCY STOP o SAME WITH AUTOMATIC RECOVERY

CHART 8



SIMPLIFIED SCHEMATIC DIAGRAM AND EXAMPLE OF A SINGLE MACHINE FLEXIBLE MACHINING SYSTEM OR "MODULE" WITH A HORIZONTAL SPINDLE MACHINING CENTER AND AN 8-PALLET MATERIAL HANDLING TURN TABLE (Niigata Engineering)

CHART 9



SIMPLIFIED SCHEMATIC DIAGRAM OF A "WORK CELL" OR "CELL" WITH 2 CNC LATHES, AN INSPECTION MACHINE 2 CONVEYORS AND A MATERIAL HANDLING ROBOT (Lodge & Shipley)

CHART 10

Multi-Station, Towline Material Handling System, Computer Controlled, Flexible Manufacturing System

DATE INSTALLED:

PHASE 1 1979
2 FUTURE

SYSTEM COMPONENTS:

PHASE 1

7 5-AXIS MILWAUKEE-MATIC MODU-LINES

3 VERTICAL TURRET LATHES

PALLET STORAGE

TOWLINE MATERIAL HANDLING SYSTEM

COMPUTER CONTROL

PHASE 2

4 5-AXIS MILWAUKEE-MATIC MODU-LINES

FUTURE MACHINES

OVERALL SYSTEM SIZE

200' 152'

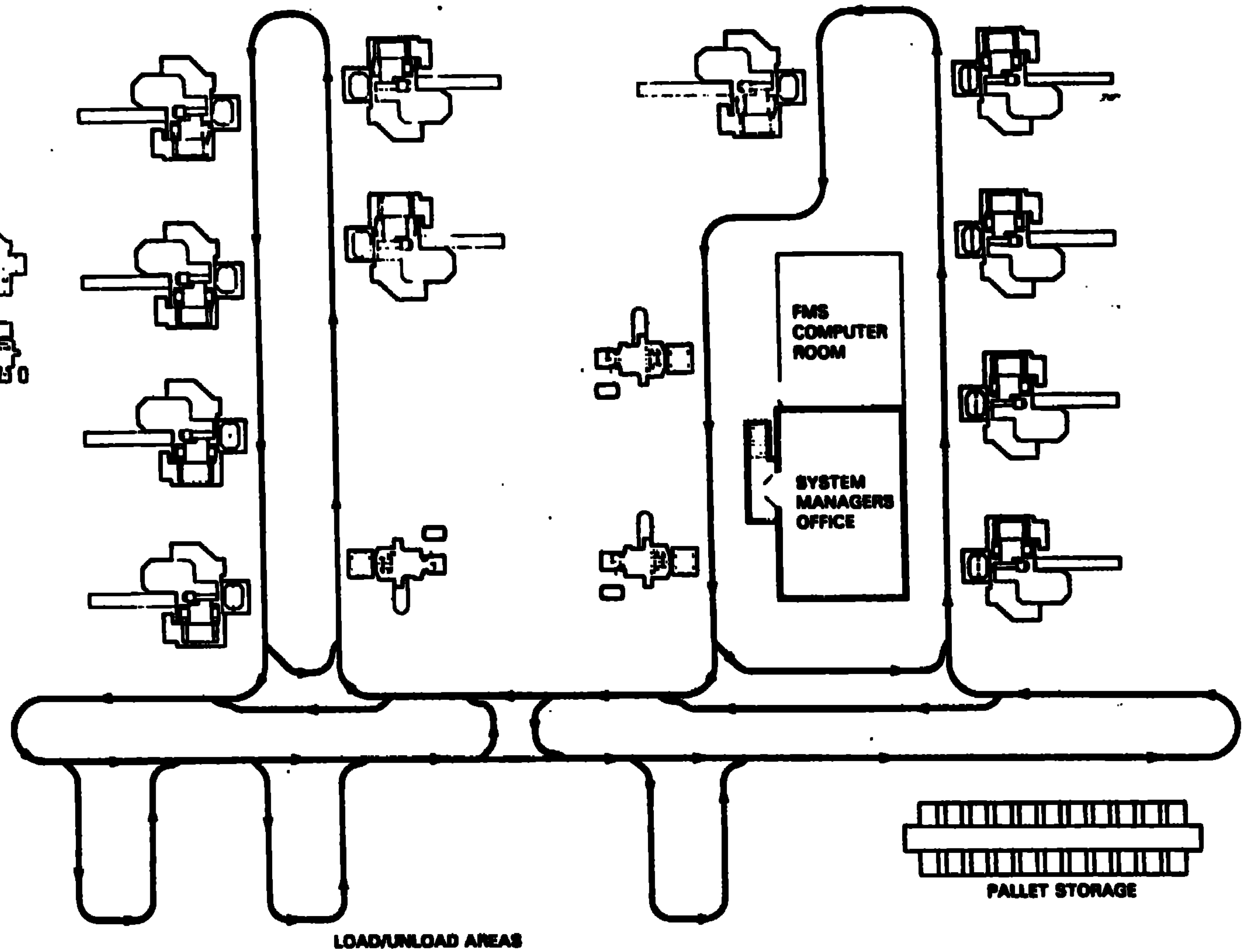


CHART 11

Courtesy Kearney & Trecker

DIFFERENT WAYS OF CLASSIFYING FMSs BY

- NUMBER OF MACHINE TOOLS IN SYSTEM
- SIZE, WEIGHT OF PART
- PART COMPLEXITY
- VOLUME RATE OR THROUGH PUT
- SIZE OF BATCH (DEGREE OF DEDICATION)
- VARIETY/NUMBER OF DIFFERENT PARTS
- MATERIAL HANDLING/TRANSFER CONCEPT
- TYPE OF CONTROL
- TYPE OF PROCESS
- TYPE OF MACHINE TOOL (E.G. HEAD CHANGER)
- FLOOR LAY-OUT/SPACE ARRANGEMENT
- DEGREE OF UNATTENDED OPERATION

SELECTED AUTOMATIC MANUFACTURING SYSTEM BUILDERS IN USA

COMPANY	LOCATION	OWNER
ACME-CLEVELAND CORPORATION	CLEVELAND, OH	
BENDIX CORPORATION	SOUTHFIELD, MI	
CNCINNATI-MILACRON, INC.	CINCINNATI, OH	
CROSS & TRECKER	BLOOMFIELD-HILLS, MI	
EX-CELL-O CORPORATION	TROY, MI	
GIDDINGS & LEWIS INC.	FOND-DU-LAC, WI	ACMA INT'L
INGERSOLL MILLING MACHINE CO.	ROCKFORD, IL	
F. JOS. LAMB COMPANY	WARREN, MI	
LUCAS MACHINE TOOL	CLEVELAND, OH	LITTON INDUSTRIES
MAZAK CORPORATION	FLORENCE, KY	YAMAZAKI MACHINERY WORKS
MOTCH & MERRYWEATHER	CLEVELAND, OH	OERLIKON
LODGE & SHIPLEY COMPANY	CINCINNATI, OH	
OLOFFSON CORPORATION	LANSING, MI	JOHN BROWN & CO.
UNIMATE	STANDFORD, CT	WESTINGHOUSE
WHITE-SUDSTRAND MACHINE TOOL CO. DIV.	BELVIDERE, IL	WHITE CONSOLIDATED INDUSTRIES

CHART 13

SELECTED FOREIGN FMS BUILDERS AND DEVELOPERS

West Germany

- Nabenfabrick Alfing Kessler GmbH, Aalen-Wasserelfingen
- Robert Bosch GmbH, Karlsruhe
- Burkhardt & Weber GmbH, Reutlingen
- Maschinenfabrik Diedesheim GmbH
- Droop & Rein, Bielefeld
- Gildemeister AG, Bielefeld
- Heckler and Koch GmbH, Oberndorf
- Gebrueder Heller Maschinenfabrik, Nuertingen
- Heyligenstaedt Werkzeugmaschinenfabrik GmbH, Giessen
- Gebrueder Honsberg Sondermaschinen, Remschneid
- Hüller-Hille Werkzeugsmaschinen GmbH, Ludwigsburg
- Liebherr Verzahntechnik GmbH, Kempten (Gear-making FMS)
- Maho Werkzeugsmaschinenbau, Bable & Co.
- Mauserwerke, Oberndorf
- Scharmann GmbH, Muenchen-Gladbach
- Bernhardt Steinel Werkzeugsmaschinen-fabrik GmbH, Schwenningen
- Fritz Werner Gruppe, Berlin

Switzerland

- Starr Fraesemaschinen AG, Rohrschach
- Mikron-Haesler SA, Boudry

Japan

- Hitachi Seiki Company, Ltd., Abiko City
- Ikegai Iron Works, Ltd., Tokyo
- Makino Milling Machine Company Ltd., Niigata
- Shin Nippon Koki Co., Ltd., Osaka
- Takizawa Machine Tool Company Ltd., Okayama City
- Toshiba Machine Company Ltd., Numazu
- Toyama Machine Works Ltd, Toyama
- Toyoda Machine Works, Ltd., (part of Toyota Motor Co.) Kariya City
- Wasino Machine Company Ltd., Komaki City
- Yamazaki Machinery Works Ltd., Nagoya

Italy

- Comau Industriale S.p.A. (Fiat), Torino
- JOBS S.p.A., Piacenza
- Rino Berardi S.p.A., Brescia
- Olivetti Controllo Numerico S.p.A., S.Bernardo D'Ivrea

Norway

- SINTIF, Trondheim

Sweden

- SMT-Pullmax AB, Goteborg

France

- Citroën, Paris
- Renault Outillages et Equipements, Boulogne-Billancourt & Renault SEIV
- Graffenstaden, Div of Cit-Alcatel, Paris

East Germany

- Fritz Heckert Kombinat, Karl Marx Stadt
- Hermann Matern, Zerbst
- Herbert Warnke Umformetchnik, Erfurt

Czechoslovakia

- Skoda, Plsen
- Tos Turim Organization
- VUOSO, Research Institute for Machine Tools & Machining, Prague
- ZAPS, Gottwaldov

USSR

- Minsk Factory of Automated Mfg., Systems, Minsk
- Institute for Technical Cybernetics, Minsk
- United R&D Institute (ENIMS), Moscow

United Kingdom

- Kearney & Trecker Marwin, Ltd., Brighton
- Amchem Co., Sileby, Leicestershire

CHART 14

MERITS OF FMS TO USER

- FLEXIBLE RANDOM PROCESSING OF BATCHES
- REDUCED FABRICATION COST PER UNIT
- BETTER AND/OR MORE CONSISTENT QUALITY
- LOWER DIRECT LABOR COST
- REDUCED INVENTORY, REDUCED WORK IN PROCESS
- REDUCED TOOLING COST
- REDUCED FLOOR SPACE
- ABILITY TO QUICKLY INTRODUCE NEW/MODIFIED PARTS
- LOW REORDER COST (NEXT BATCH)
- LESS FABRICATION TIME (LESS LEAD TIME)
- VARIABLE PART MIX
- LESS PAPER WORK, CAN INTERFACE WITH PLANT-WIDE FABRICATION CONTROL SYSTEM
- LESS IN-PLANT MATERIALS TRANSFER
- AUTOMATIC WORK MEASUREMENT (COST CONTROL)
- REDUCED DOWNTIME WITH BETTER DIAGNOSTICS
- MANAGEMENT (RATHER THAN OPERATOR) CONTROLS SCHEDULE, COST OR QUALITY
- POTENTIAL IMPROVED COMPETITIVE COMPANY POSTURE

KEY FACTORS IN SUCCESS OF FMS

- o FAVORABLE BUSINESS CLIMATE
  - MARKET POTENTIAL FOR PRODUCT
  - PROFIT POTENTIAL FOR PRODUCT LINE
- o FAVORABLE PLANT SITUATION
  - LOCATION
  - PLANT CAPACITY
  - MATERIAL SUPPLY
- o MANAGEMENT INTEREST AND SUPPORT
  - LONG TERM COMMITMENT
  - VALID 5 TO 10 YEAR FORECAST (FUTURE PRODUCTS, QUANTITIES)
  - MANAGEMENT PARTICIPATION
  - COMPANY POLICY
- o FMS APPLICATION IS RIGHT
  - ALLOWS HIGH UTILIZATION OF INDIVIDUAL MACHINES
  - ALL PARTS READILY FIT PART FAMILIES
  - VOLUME IS APPROXIMATELY CONSTANT FOR 5 TO 10 YEARS
- o COMPANY HAS FAVORABLE BACKGROUND EXPERIENCE
  - IN SPECIFIC PRODUCT LINE
  - IN CNC MANUFACTURING, PROGRAMMING

CHART 16